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RESEARCH ARTICLE

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The contribution of household fruit and vegetable growing to fruit and vegetable self-sufficiency and consumption

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Societal Impact Statement

Household fruit and vegetable (F&V) production in allotments and gardens can provide sustainable access to nutritious food. The present study demonstrates that UK household F&V production supplies more than half of the vegetables and potatoes and 20% of the fruit that growers consume annually. Importantly, study participants ate 6.3 portions of their recommended 5-a-day F&V (70% higher than the UK national average), and their wasted F&V was 95% lower than the national average. This provides key evidence to demonstrate the role household F&V production could play in providing access to fresh F&V, which is key to a healthy, food-secure population.

Summary

- Improving access to and consumption of fruits and vegetables (F&V) is crucial to a healthy and food-secure population, as current low intakes are linked to high rates of non-communicable diseases, premature death and increased healthcare costs. Household F&V production could improve diet quality and food system resilience, however, quantitative evidence for its potential is limited.
- We studied year-long F&V production, purchases, donations and waste in UK food-grower households ($N = 85$) using a food diary approach.
- Median year-round household self-sufficiency was 51% in vegetables, 20% in fruits and 50% in potatoes. The median daily per capita F&V intake was 507 g, which is the equivalent of 6.3 portions of F&V and 70% higher than the UK national average. On average, own production accounted for half of each household's annual 5-a-day F&V requirements. F&V waste was negligible, equivalent to 0.12 portions per day and 95% lower than the UK average F&V waste.
- We demonstrate that promoting household F&V production could improve food system resilience, diet-related public health and sustainability.

KEYWORDS

diet quality, food security, fruits and vegetables, public health, resilience, sustainability, urban horticulture

1 | INTRODUCTION

Eating a balanced diet is essential for maintaining health and preventing a range of diseases. The World Health Organisation's (WHO) recommendations for a healthy diet include consuming at least 400 g of a range of fruits and vegetables (F&V) daily (excluding starchy tubers), as well as limiting saturated fat, salt and free sugar intake (WHO, 2020). Sufficient F&V consumption has been shown to reduce the risks of malnutrition, developing obesity and non-communicable diseases, including cardiovascular disease, type 2 diabetes and certain types of cancer (Bazzano et al., 2003; Wang et al., 2014; WHO, 2003). However, even in high-income countries, eating a healthy diet high in F&V can be a challenge for many people due to issues of financial and physical access as well as other factors such as culinary culture (Dimbleby, 2021; FAO et al., 2020).

In the UK, despite national efforts to promote F&V consumption (NHS, 2018), most people do not eat their '5-a-day' (i.e., five 80-g portions), a target set by the UK government informed by the WHO target to consume at least 400 g of F&V a day. Although recent years have seen a slight increase, average per capita F&V intake in the country is 26% below recommendations, with only about 8% of teenagers and less than a third of adults meeting the 5-a-day target (BDA, 2020; NHS Digital, 2019; PHE, 2019). The situation is similarly worrying in the US and EU countries, where current guidelines for F&V consumption are met by less than 20% and around 12% of the population, respectively (Eurostat, 2022; USDA, 2020). There are also large and growing socio-economic inequalities in the access to and consumption of F&V, with the poorest 20% of the UK population eating a full portion less a day than the richest 20%, which can be linked to prevailing disparities in health status (PHE, 2019). Significant associations between socio-economic status and F&V intake can be observed in the US and Europe (Ball et al., 2015; Dubowitz et al., 2008; Jack et al., 2013). It is estimated that diets low in F&V contribute to around 18,000 premature deaths in the UK every year (Afshin et al., 2019) and that food-related ill health costs the NHS about £6 billion annually (Rayner & Scarborough, 2005). Globally, diet-related health costs linked to mortality and non-communicable diseases are predicted to exceed USD 1.3 trillion per year by 2030 (FAO et al., 2020). We are facing a diet-related health crisis, with soaring rates of obesity and non-communicable disease placing a heavy burden on both affected individuals and society as a whole (Food Foundation, 2017; NHS Digital, 2020).

In addition, the COVID-19 pandemic and now the rising food prices related to Brexit and the current turbulence in Ukraine have highlighted the fragility of our globalised supply chains and the existing issues of food insecurity for growing urban populations (FAO, 2020; FAO et al., 2020; Revoredo-Giha & Costa-Font, 2020; Sweney, 2022). It has become clear that, in order to prepare for further disruptions associated with the unpredictable effects of climate change and political and economic turmoil on global agri-food systems, we must increase the resilience of our food system and reduce inequalities related to diet. The UK government's new food strategy advocates for increasing domestic food production as a key way of providing national resilience against disruptions to foreign supplies and for adopting longer-term measures to improve access to and affordability of healthy food for all to combat obesity and diet-related illnesses (Defra, 2022). Given the importance of F&V for health and our relatively low and decreasing national production of these foods, increasing and diversifying domestic F&V production should be a priority (Defra, 2020; Dimbleby, 2021; Ingram et al., 2020; Tendall et al., 2015).

The supply shortages that followed the outbreak of the pandemic drew increased attention to the potential of urban horticulture to improve food security and nutrition (FAO, 2020; Lal, 2020). F&V production on allotments (plots of land of approx. 250 m^2 rented to individuals for crop production) and domestic gardens made an important contribution to the UK war effort during World War II, providing 18% of the national F&V supply (Defra, 2017; Ginn, 2012), and now once again it could play a role in improving our food system. Research has demonstrated that own-grown crop yields can be similar to those achieved by conventional production (Edmondson, Childs, et al., 2020) and that there is potential in urban areas for horticulture to meet a significant proportion of the F&V demands of its inhabitants (Edmondson, Cunningham, et al., 2020). Moreover, household F&V production could improve diet quality by providing access to F&V as well as potentially triggering healthier food behaviours (Kourmpetli et al., 2022), and while they do not count towards the 5-a-day, potatoes are a nutrient-rich staple in the country, and their household production could make an important contribution to food security (Burgos et al., 2020). Although the horticultural production potential of urban green spaces has been estimated on the national (Walsh et al., 2022) and city scales (Edmondson, Cunningham, et al., 2020), quantitative data on the level of household self-sufficiency that could be achieved by household food production and evidence for a relationship between growing F&V and increased household F&V intake in the UK have thus far been lacking. The aim of this research is to quantify the potential contribution of household F&V production to the self-sufficiency and F&V consumption of food-grower households in the UK, as well as to investigate how this may vary with certain characteristics of people's growing practices, to better understand ways in which to increase its potential. We studied year-round crop production, purchases, donations and crop waste in 85 food-grower households to answer the questions:

- What levels of year-round production and self-sufficiency can food-grower households achieve with different types of produce, and how does this vary across the year?
- How much F&V do people in food-grower households eat, and how diverse is their F&V consumption?
- How do certain aspects of growing practice (i.e., cultivated area, grower experience, gardening effort) and household size affect household food productivity and self-sufficiency?

2 | MATERIALS AND METHODS

2.1 | Participants

One hundred and ninety-seven people engaged in food growing (including allotment holders and home gardeners) were recruited on a voluntary basis from across the UK through conventional and social media and via word of mouth in the gardening community (including through collaboration with the National Allotment Society, Royal Horticultural Society, and the network of the ongoing MYHarvest project [myharvest.org.uk]). Recruitment started in July 2020. Participants kept a year-long record of their fruit and vegetable (including potatoes) production, purchases, foraging, donations and waste. We acknowledge that participants in this study were a self-selecting group of typically experienced growers and that the study period of 2020–2022 was impacted by major COVID-19 lockdowns, which meant that participants likely had more time to tend to their allotments and home gardens than under normal circumstances, so the data may not be fully representative of typical practice. Complete records (i.e., including at least 42 weeks, 80% of the year) were received from 85 participants by February 2022. The project was granted ethical approval by the Department of Animal and Plant Sciences, The University of Sheffield (project ref. 035588).

2.2 | Data collection

A diary-based approach was employed as it enabled the collection of the long-term data needed to fully understand the contribution of household food growing to diet across a full year. However, we acknowledge that there are known limitations to diary keeping as a data collection method related to the accuracy and completeness of the data (see, e.g., Fuller et al., 2017). Volunteers were provided with a diary ('MYHarvest Diary') via post, in which each week they recorded the weights (in grams) of all fruits and vegetables (F&V), including fresh, frozen, tinned, canned and dried produce, they acquired that week, indicating its source (i.e., their allotment, home garden, a shop or market, gift from other growers or foraged in the wild) for a full year, that is, 52 weeks (data collection started in the summer of 2020, but exact date ranges of records varied among participants). We did not collect data on the consumption of foods acquired before but consumed after the study period or on the amounts of produce that were recorded, stored and not consumed until after the study period. We made the assumption that amounts of food used from and added to storage would roughly balance out over a year. Ingredients within ready meals/takeaways or foods otherwise prepared and eaten outside the home were not quantified, but we did collect data on the frequency of eating such meals to ensure that diary records largely reflected participants' total fruit and vegetable consumption. Participants also recorded the approximate number of hours they spent food gardening (including sowing, weeding, watering and harvesting) each week, how much, if any, of their produce they gave away or went to waste, whether they froze or preserved any produce, or whether they used previously frozen or preserved produce. Additional information collected included household size (indicating the number of people fed by documented amounts of produce), how often participants ate outside the home (takeaways/restaurant meals), how long they had practiced food growing for (number of years), total allotment size, allotment food growing area, garden food growing area, whether participants grew food organically, and what percentage of their total F&V consumption they thought was provided by their own produce (the full list of questions and an example weekly sheet from the diaries can be found in Figures S1–S3). After 52 weeks, completed diaries were posted back to Sheffield, where their contents were anonymised and entered into a spreadsheet.

2.3 | Data processing

Each recorded food item was classified as a fruit, vegetable, potato or nut (potatoes and nuts were excluded from analyses looking at F&V consumption because they do not contribute towards the 5-a-day but were included in assessments of own produce yields and household self-sufficiency). Fruits and vegetables were differentiated based on their nutritional properties, such that more nutrient-dense foods (i.e., those with higher sugar or fat content), including those typically consumed as fruits as well as avocados and olives, were classified as fruits, while those lower in sugar and fat, including most culinary vegetables, legumes, herbs and sweet potatoes, were classified as vegetables.

Herbs harvested in very small quantities (which participants were not required to weigh) were all assigned a weight of 1 g. In cases where only the number of food items acquired was recorded, weight was estimated based on typical supermarket weight. On a few occasions (i.e., 1 week year^{-1} in three diaries), when participants forgot to record the weights of shop-bought produce but noted that amounts were very similar to the previous week, that week's data was copied to fill in the missing weights. In rare cases (i.e., on average less than three times in a year-long record, with the maximum number of occurrences per diary being 9), when only the type of produce was recorded, it was assumed that either one piece or the amount contained in a typical supermarket pack (e.g., a pack of six apples) was harvested or purchased, whichever seemed more realistic based on the type of produce and the participant's previous records. Where 'a few' items were listed, this was assumed to refer to four pieces, while 'a small amount' was assigned an arbitrary weight of 50 g (a list of the exact values used to complete missing data can be found in Table S1). In total, 1.4% of our data comprised imputed values according to the above assumptions. To test the effect of using imputed values to complete missing data on our estimates of produce consumption, production and self-sufficiency, we reran these analyses on an alternative version of the data where a weight of 0 g was assigned to all incomplete observations. We found the results of alternative analyses to be very similar

(Tables S2 and S3). We provide results using data including imputed values in Section 3.

Recorded weights of dry fruit and juice were converted to equivalent fresh weight based on portion sizes defined by the British Nutrition Foundation (i.e., 30 g dried fruit or 150 mL juice = 80 g fresh weight), and weights of dry pulses were converted to cooked weight (assuming 100 g dry beans or chickpeas = 200 g when cooked, 100 g dry lentils or peas = 250 g when cooked). Jams and chutneys were assumed to have a 50% fruit content by weight. Half a can of vegetable soup was counted as one vegetable portion (i.e., 200 g counted as 80 g). Other vegetable-containing food products (e.g., vegetable burgers) were assumed to have a 10% vegetable content by weight. Because of their high fat and salt content, vegetable crisps, recorded by a few participants, were excluded from estimations of vegetable consumption. Tofu, soy mince and vegetarian meat alternatives not made from whole vegetables were also excluded. Although pulses and fruit juice/smoothies can only count as one portion a day regardless of the amount consumed, where larger quantities of these foods were recorded, it was assumed that these were consumed over a period of time, not exceeding the daily maximum, so the full recorded amounts were included in estimations of annual F&V intake.

2.4 | Analysis

2.4.1 | Household produce consumption, production and self-sufficiency

Total weights of different types of produce consumed in participating households over the course of the year, overall and as acquired from different sources, as well as weights of produce given away and amounts of waste, were calculated by adding up all recorded weight values within each category. The annual self-sufficiency of participating households in all produce, fruits, vegetables and potatoes was calculated as the proportional contribution of own-grown produce to total gross annual consumption.

2.4.2 | Fruit and vegetable (F&V) consumption

The mean per capita F&V intake in participating households was estimated by dividing net annual household F&V consumption (i.e., gross consumption minus donations and waste) by the number of people in the household and the number of days for which records were available (i.e., 7 × [52 − number of weeks without records]). F&V weight was converted to the number of daily portions such that one portion equals 80 g of fresh, canned, tinned or frozen produce, 30 g of dried fruit or 150 g of pure juice. Diversity in F&V consumption was assessed as the number of types of F&V consumed in participating households over the course of a year. We used a dependent sample t-test to compare the mean number of fruits and vegetables consumed in each household.

2.4.3 | Predictors of own food production and self-sufficiency

To investigate the potential effects of a number of factors that could affect own food production (total annual weight and yield per m^2) and household produce self-sufficiency (% by weight), we used multiple linear regression analyses to test associations with food growing area (m^2), gardener experience (number of years growing food), cultivation effort (mean weekly number of food gardening hours and mean number of allotment visits per week), yearly allotment rent (as a possible indicator of the availability of communal resources and services provided by allotment societies) and household size (to indicate the number of people consuming their own produce). Models for each outcome were built such that first, all hypothesised predictors (a different set for each outcome, based on hypothesised relationships and inspection of data) were entered simultaneously to create a full model, and then, after checking and, if necessary, correcting for the assumptions of linearity (using scatter plots and residual diagnostic plots), multicollinearity (based on variance inflation factors [VIF]) and the presence of potential outliers (based on standardised residual distribution) and influential cases (based on Cook's distance and leverage plots), explanatory variables that did not have a significant effect on the outcome were removed one by one, starting with the one with the highest p-value. After each removal, the performance of the reduced model was compared with the previous model using the Akaike Information Criterion (AIC), and the model with the lower AIC was selected. The process was repeated until further removal of predictors did not result in improved model fit. Regression parameters were reported for the final, best-fit model for each outcome. To assess the generalisability of our best-fit models, assumptions of normal standardised residual distribution and homogeneity of residual variance were evaluated. We also assessed the strength of the correlation between calculated levels of F&V self-sufficiency and levels perceived by participants using Pearson's r. All analyses were carried out in R (version 4.0.3).

3 | RESULTS

3.1 | Participants and their growing practice

Over two thirds (67.1%) of participants (N = 85) used both an allotment and their home garden to grow food crops, 16.5% used only their allotment, and 16.5% used only their home garden (see Table S4 for descriptive statistics on participants' growing practices). The median food-growing experience among participants was 20 years, ranging from 6 months to 60 years. The majority of participants fully (75.3%) or mainly (5.9%) adopted organic gardening methods. The median total cultivated area used for food production was 120.5 m^2. On average, participants spent just under 4 h food gardening per week, and those who had an allotment visited their plot between two and three times a week. Over half of the produce recorded (53.9%) was purchased at supermarkets or markets; nearly a third (31.5%) was grown on participants' allotments; 12.5% in home gardens; 2.1% was received from other growers; and 0.1% was acquired by foraging (Table S5). All participants produced vegetables, while fruits and potatoes were each grown by 98% of participants. Participants on average cultivated 37.5 ± 1.3 different F&V crops, typically growing around four times more vegetable than fruit crops. Excluding potatoes, the most frequently grown vegetables were tomatoes, courgettes, beetroot, rhubarb, carrots, onions, leeks, lettuce, beans, peas, cucumbers and cabbage, each of which was grown by over two-thirds of participants. The most frequently grown fruits were apples, raspberries, strawberries, blackcurrants and gooseberries, each of which was produced by over 50% of participants. Ninety-five percent of participants gave away some of their produce; 72% received produce from other growers; and 19% foraged for food in the wild. Ten participants reported no produce waste during the study year, and several participants noted that they composted or fed their food waste to livestock as a means of sustainable disposal (as data was not specifically collected on composting/livestock feeding, the actual number of participants engaging in such practices is unknown). Nearly all participants froze or preserved some produce during the study year and used their previously frozen or preserved produce (Table S6). Freezing and preservation were more common between June and November than during the rest of the year (Figure 1a,b). Using previously frozen or preserved produce was slightly less common in the summer months but was relatively common throughout the year (>60% of participants in every month) (Figure 1c,d).

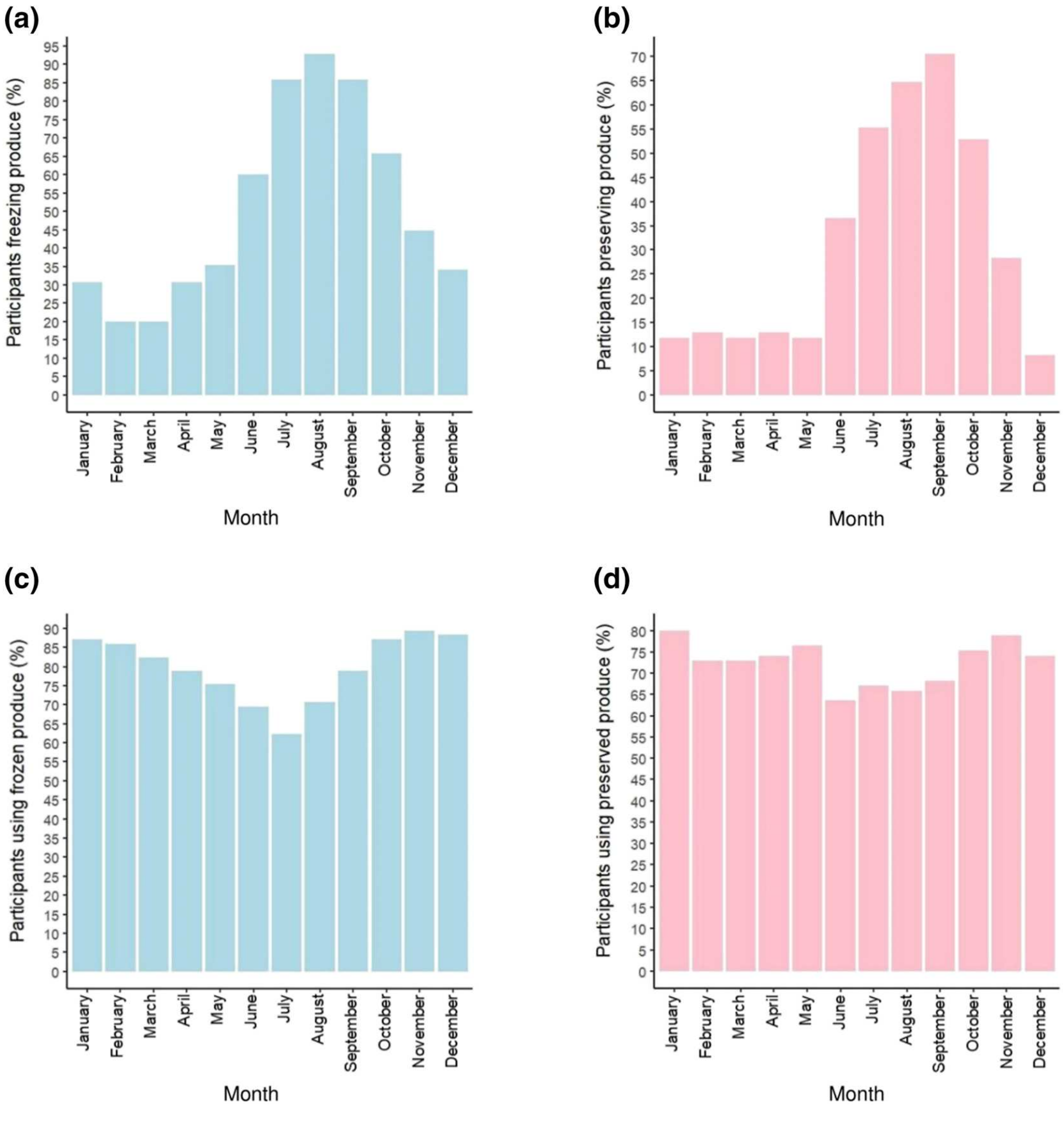

FIGURE 1 Percentage of UK food-grower households participating in the project (N = 85) (a) freezing, (b) preserving, (c) using frozen and (d) using preserved produce in different months of the year. Data related to produce freezing (a and c) are shown in blue, data related to preserving (b and d) are shown in pink.

3.2 | Annual produce fluxes in food-grower households

Household mean gross produce consumption was 464.1 kg year^{-1} ± 23.6 (S.E.), which comprised 250.3 kg year^{-1} ± 13.1 (S.E.) vegetables, 150.4 kg year^{-1} ± 11.1 (S.E.) fruits, 62.9 kg year^{-1} ± 4.7 (S.E.) potatoes and 0.8 kg year^{-1} (median) nuts (recorded by 23.5% of participants) (Table S2). Participants on average consumed one takeaway or restaurant meal per month (MED = 0.25 meal per week), the ingredients of which were not captured by our study. The median weights of fruit, vegetable and potato purchases were 104.5, 116.9 and 28.7 kg year^{-1}, respectively. The median weights of fruits, vegetables and potatoes grown by participants were 26.6, 107.1 and 24.2 kg year^{-1}, respectively (Figure 2a). The median weights of produce given away ($n = 81$) and received from other growers ($n = 72$) by participants were 16.1 and 3.8 kg year^{-1}, respectively. The mean amount of food acquired by foraging among those who foraged during the study year ($n = 19$) was 0.5 kg ± 0.2 (S.E.) (across all participants, the contribution of foraging to annual consumption was negligible). The median weight of produce waste was 3.4 kg year^{-1}, less than 1% of total consumption.

3.3 | Own crop yield and household produce self-sufficiency

The median production on allotments was 151.6 kg year^{-1} (Table S2). The median production in home gardens was 23.9 kg year^{-1}. Total household (allotment and garden) crop production ranged between 34.2 and 588.7 kg year^{-1}, with a median of 163.6 kg year^{-1} (Figure 2a). The median own-grown produce yield was 1.4 kg m^{-2} year^{-1}. The median year-round produce self-sufficiency among participants was 41.1%, ranging from 14.9% to 92.3% (Figure 2b). Year-round median self-sufficiency in potatoes was 49.7%, in vegetables, 51.1%, and in fruits, 20.2%. Replacing imputed values of crop weight with 0 g had a small effect on these results; for

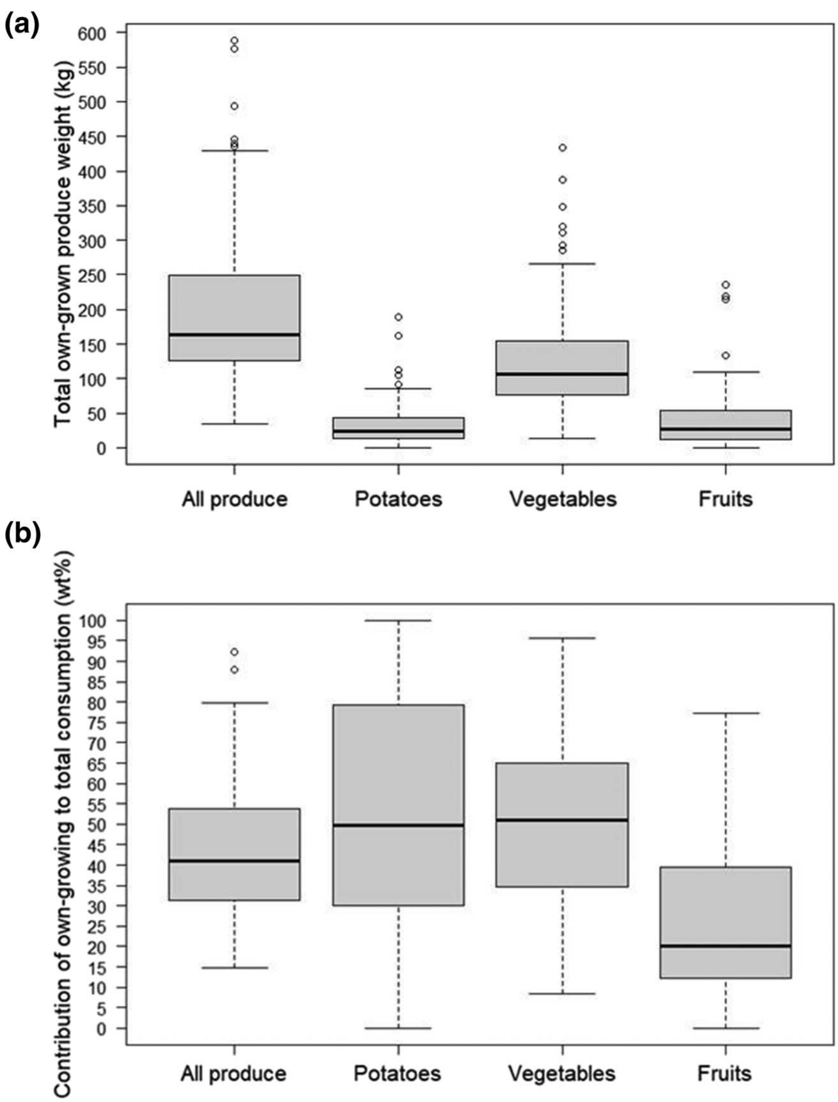

FIGURE 2 Total weights (kg) of different types of produce grown in UK food-grower households participating in the project (N = 85) over the course of a year (a) and annual household self-sufficiency (percent by weight of total annual household consumption, wt%) (b) in all produce, potatoes, vegetables and fruits. Boxes represent the 25th, 50th and 75th percentiles; error bars show 95% confidence intervals; and circles represent outliers.

example, mean annual household F&V self-sufficiency increased from 42.6% ± 2.0 to 43.4% ± 2.1 (Tables S5 and S6). On average, own F&V production accounted for half of participants' annual household 5-a-day requirements (MED = 49.8%), providing 1.9 portions of vegetables and 0.5 portions of fruit for each person in the household. Levels of year-round household F&V self-sufficiency calculated from consumption records were strongly correlated with levels of self-sufficiency perceived by participants ($r_{(72)} = 0.70$, $p < .001$).

Own-grown food production varied across the year (Figure 3a). Median weights of own-grown produce were lowest in February (1.2 kg), increasing gradually to their highest level in August (54.2 kg). Harvest weights from December to May were generally low (i.e., median <3.8 kg) and much less variable among participants than during the more productive months of the year. Weights of purchased produce varied relatively little across the year but showed a slight decrease from May to September, then an increase through the winter (Figure 3b). The median weights of monthly produce waste were 0 kg

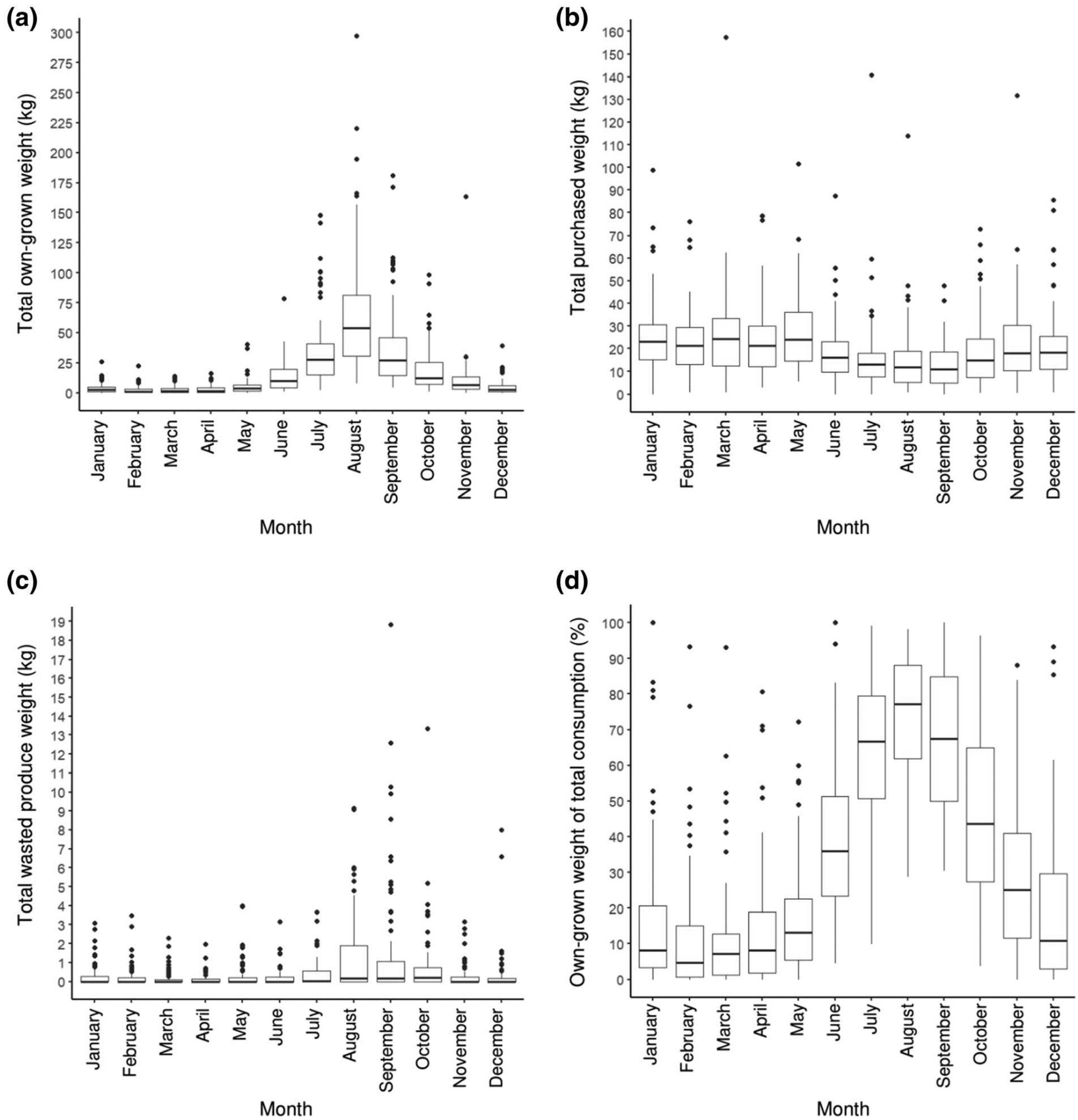

FIGURE 3 Total weights of (a) own-grown, (b) purchased and (c) wasted produce, and (d) percentage by weight of own-grown produce of total monthly household produce consumption across UK food-grower households participating in the project (N = 85) in each month of the year. Boxes represent the 25th, 50th and 75th percentiles; error bars show 95% confidence intervals; and dots represent outliers (see Tables S7 to S10 for corresponding data).

during most of the year, except from July to October, when it increased slightly to up to 0.2 g month^{-1} (Figure 3c). The median monthly produce self-sufficiency ranged from 4.8% in February to 77.2% in August, with levels over 50% from July to September (Figure 3d).

3.4 | Fruit and vegetable consumption

The median per capita F&V intake in participant households was 507.3 g day^{-1}, the equivalent of 6.3 80-g portions (Figure 4 and Table S2). Replacing imputed values of crop weight with 0 g had a very small effect on these results (Table S3). The median per capita fruit and vegetable intakes were 2.3 and 3.9 portions, respectively. The mean number of F&V crop types consumed in households over a year was 69.6 ± 2.0 (S.E.), ranging from 32 to 118. Participants typically consumed more than twice as many types of vegetables as fruits (48.4 ± 1.4 [S.E.] vs. 21.9 ± 0.8 [S.E.]), respectively (dependent t-test $t_{[84]} = 22.37$, $p < .001$).

3.5 | Predictors of own food productivity

The best-fit linear model for annual household crop production (kg year^{-1}) in the study population included food growing area, frequency of allotment visits, grower experience and household size (Table 1). On average, annual harvest weight increased by 27.2 kg ± 6.9 for each additional weekly allotment visit, by 2.6 kg ± 0.7 for each additional year of grower experience, and by 0.4 kg ± 0.1 for each one m^2 increase in food growing area. The effect of household size was not significant ($p = .088$). The best fit model for annual

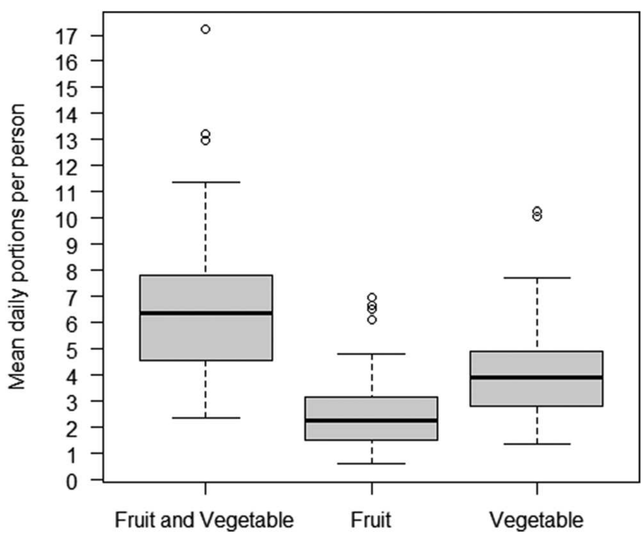

FIGURE 4 Mean per capita daily fruit and vegetable intakes (number of 80 g portions) in UK food-grower households participating in the project (N = 85). Boxes represent the 25th, 50th and 75th percentiles; error bars show 95% confidence intervals; and circles represent outliers.

produce yield (kg m^2 year^{-1}) included food growing area, grower experience, household size, the mean weekly number of food gardening hours and the mean number of weekly allotment visits (Table 2). Produce yield increased by 0.33 kg m^2 year^{-1} ± 0.16 for each additional person in the household, by.02 kg m^{-2} year^{-1} ± 0.01 with each year of grower experience and decreased by 0.005 kg m^{-2} year^{-1} ± 0.001 with each m^2 total cultivated area. The frequency of allotment visits and the amount of time spent gardening did not have significant effects ($p = .098$ and $p = .170$, respectively).

Year-round household produce self-sufficiency was best described by a model containing food growing area, grower experience, frequency of allotment visits and household size (Table 3). On average, household produce self-sufficiency increased by 3.6% ± 1.1 with each additional weekly allotment visit and by 0.05% ± 0.02 with each m^2 of total cultivated area. The effects of grower experience and household size were not significant ($p = .058$ and $p = .063$, respectively). Potato self-sufficiency increased by 0.5% ± 0.2 for each additional m^2 of total food growing area, by 6.1% ± 1.8 with each additional weekly allotment visit, and by 0.2% ± 0.1 for each £1

TABLE 1 Results of multiple regression analysis of the effect of characteristics of food growing practice on annual household food crop production (kg year^{-1}).

Predictors	B (SE)	p
Constant	−61.18 (55.43)	.274
Total food growing area (m^2)	**0.39** (0.13)	<.01
Mean allotment visits per week	**27.15** (6.92)	<.001
Grower experience (years)	**2.59** (0.68)	<.001
Household size (persons)	31.88 (18.39)	.088

Note: Predictors and regression coefficients in the table are derived from our best-fit model for the outcome based on the Akaike information criterion (AIC). Predictors in the initial full model also included yearly allotment rent and the mean weekly number of hours spent food gardening, but these were dropped in the process of improving model fit. Figures in bold are statistically significant at the 5% level ($p < .05$). Model $R^2 = 0.39$, $F_{(4, 60)} = 9.6$, $p < .0001$.

TABLE 2 Results of a multiple regression analysis of the effect of characteristics of food growing practices on annual household produce yields (kg m^{-2} year^{-1}).

Predictors	B (SE)	p
Constant	0.47 (0.49)	.345
Total food growing area (m^2)	−**0.005** (0.001)	<.0001
Mean weekly food gardening hours	0.09 (0.05)	.098
Mean allotment visits per week	0.14 (0.10)	.155
Grower experience (years)	**0.02** (0.01)	<.01
Household size (persons)	**0.33** (0.16)	<.05

Note: Predictors and regression coefficients in the table are derived from our best-fit model for the outcome based on the Akaike information criterion (AIC). All predictors included in the initial full model were retained. Figures in bold are statistically significant at the 5% level ($p < .05$). Model $R^2 = 0.49$, $F_{(5, 58)} = 11.0$, $p < .0001$.

TABLE 3 Results of a multiple regression analysis of the effect of characteristics of food growing practices on annual household produce self-sufficiency (percent by weight of total annual household consumption).

Predictors	B (SE)	*p*
Constant	**34.46** (8.55)	<.001
Total food growing area (m^2)	**0.05** (0.02)	<.05
Mean allotment visits per week	**3.55** (1.07)	<.01
Grower experience (years)	0.20 (0.10)	.058
Household size (persons)	−5.38 (2.84)	.063

Note: Predictors and regression coefficients in the table are derived from our best-fit model for the outcome based on the Akaike information criterion (AIC). Predictors in the initial full model also included yearly allotment rent and the mean weekly number of hours spent food gardening, but these were dropped in the process of improving model fit. Figures in bold are statistically significant at the 5% level ($p < .05$). Model $R^2 = 0.30$, $F_{(4, 60)} = 6.4$, $p < .001$.

TABLE 4 Results of a multiple regression analysis of the effect of characteristics of food growing practices on annual household potato self-sufficiency (percent by weight of total annual household consumption).

Predictors	B (SE)	*p*
Constant	**36.91** (13.07)	<.01
Yearly allotment rent (£)	**0.24** (0.09)	<.05
Mean allotment visits per week	**6.12** (1.75)	<.001
Grower experience (years)	0.48 (0.17)	<.01
Household size (persons)	−10.80 (4.62)	<.05

Note: Predictors and regression coefficients in the table are derived from our best-fit model for the outcome based on the Akaike information criterion (AIC). Predictors in the initial full model also included total food growing area and mean weekly number of hours spent food gardening, but these were dropped in the process of improving model fit. Figures in bold are statistically significant at the 5% level ($p < .05$). Model $R^2 = 0.33$, $F_{(4, 64)} = 7.8$, $p < .0001$.

increase in yearly allotment rent, and decreased by 10.8% ± 4.6 for each additional person in the household (Table 4). Vegetable self-sufficiency increased by 4.7% ± 1.3 with each additional weekly allotment visit and by 0.05 ± 0.02 for each additional m^2 of total growing area (Table 5). The model for fruit self-sufficiency included total food growing area and household size, which had a small positive (0.0015% ± 0.0007 for each m^2 total growing area) and negative (−0.33% ± 0.13 for each additional person in the household) effect, respectively (Table 6).

4 | DISCUSSION

Developing the ability of the food system to provide sufficient amounts of healthy food for all and to withstand socio-economic and environmental shocks and pressures from continued rapid urbanisation and climate change is a key priority in the UK (Defra, 2022; Dimbleby, 2021) and globally (Food Security, 2022). Here, we report the first long-term study of F&V production and consumption of UK food-grower households over the course of an entire year and demonstrate that promoting household food production could play an essential role in increasing household and national F&V self-sufficiency and improving diet quality, as well as reducing waste.

TABLE 5 Results of a multiple regression analysis of the effect of characteristics of food growing practices on annual household vegetable self-sufficiency (percent by weight of total annual household consumption).

Predictors	B (SE)	*p*
Constant	**32.04** (5.99)	<.0001
Total food growing area (m^2)	**0.05** (0.02)	<.05
Mean allotment visits per week	**4.70** (1.28)	<.001

Note: Predictors and regression coefficients in the table are derived from our best-fit model for the outcome based on the Akaike information criterion (AIC). Predictors in the initial full model also included yearly allotment rent, household size, grower experience and the mean weekly number of hours spent food gardening, but these were dropped in the process of improving model fit. Figures in bold are statistically significant at the 5% level ($p < .05$). Model $R^2 = 0.21$, $F_{(2, 62)} = 8.2$, $p < .001$.

TABLE 6 Results of a multiple regression analysis of the effect of characteristics of food growing practices on annual household fruit self-sufficiency (percent by weight of total annual household consumption).

Predictors	B (SE)	*p*
Constant	**3.51** (0.31)	<.0001
Total food growing area (m^2)	**0.0015** (0.0007)	<.05
Household size (persons)	−**0.33** (0.13)	<.05

Note: Predictors and regression coefficients in the table are derived from our best-fit model for the outcome based on the Akaike information criterion (AIC). Predictors in the initial full model also included yearly allotment rent, grower experience, frequency of allotment visits and the mean weekly number of hours spent food gardening, but these were dropped in the process of improving model fit. Figures in bold are statistically significant at the 5% level ($p < .05$). Model $R^2 = 0.16$, $F_{(2, 71)} = 6.7$, $p < .05$.

Participants in our study had high levels of year-round self-sufficiency in F&V and potatoes, and their perceived levels of self-sufficiency were strongly correlated with levels estimated from their consumption records, which also adds credibility to anecdotal reports of high levels of self-sufficiency in the gardening community (Allotment Gardening - Grow Your Own, 2014; Robinson, 2022). Regular freezing and preserving of produce observed among participants could play an important role in this. The relatively higher production of vegetables by participants compared with fruits suggests that household food production may be more effective at providing vegetables. This is in line with recommendations to prioritise increasing vegetable consumption, which may provide a greater health benefit than increasing fruit consumption (EAT, 2019; The Food Foundation, 2021). In addition, food-grower households in our study produced a median of 3.4 kg F&V (including potatoes) waste over a year—since average avoidable household F&V waste in the UK is estimated to be around 68 kg $year^{-1}$ (WRAP, 2021), this suggests that household food production may be associated with waste-reducing behaviours. Indeed, giving away, preserving and freezing excess produce were common practices among participants.

Annual household crop production was positively associated with cultivated area, frequency of allotment visits and grower experience, which suggests that increasing the amount of growing space available and promoting active engagement and skill development are important for maximising the potential of household food production. Crop yields per unit area were also positively associated with household size, which could indicate that larger households were more motivated to make better use of their space or that sharing tasks among more people improved gardening efficiency.

The list of most frequently grown crops in our study was similar to that found in a case study of allotments in Leicester, likely reflecting general cultural and environmental factors in the country. However, the median annual produce yield in our study (1.4 kg m^{-2} $year^{-1}$) was lower than the mean yield in the Leicester study (2.3 kg m^{-2} $year^{-1}$), probably because of the differences in management and local environmental conditions. Unlike in the Leicester study, our data came from both allotment holders and home gardeners in various parts of the country, with various levels of engagement with food production. In addition, soil and climatic conditions are known to affect plant growth (McMahon et al., 2011), and our analyses indicate that yields are also influenced by grower experience, cultivated area and household size, which could explain the difference between the two studies.

The average F&V intake in food-grower households (6.3 portions per person per day) was over 70% higher than the national average (3.7 portions) (PHE, 2019) and included a large variety of F&V. Although we did not collect information on socio-demographic factors that could also affect F&V consumption to be able to directly link observed high F&V intakes to involvement in their own production, our results suggest that one mechanism to increase F&V consumption in the UK may be to increase engagement with household-level F&V production. Exploring mechanisms to increase F&V consumption, particularly in households with low consumption, is critical, as consuming at least five portions of F&V daily is associated with significantly decreased likelihoods of developing obesity, heart disease, type 2 diabetes and certain types of cancer (WHO, 2003), so promoting F&V consumption via improved household availability could have important positive implications for public health. Household F&V production could also help increase dietary intakes of iron, magnesium, potassium, folate and beta-carotene to prevent and reverse deficiencies (PHE, 2019), as these micronutrients can be found in relatively large amounts in many popular crops grown in our study, including green vegetables, beans and tomatoes (Roe et al., 2013). In addition, home-grown potatoes could provide an important source of carbohydrates, essential amino acids, vitamins B6 and C, potassium and antioxidants (Burgos et al., 2020), further contributing to household nutritional security.

On a national scale, wide adoption of household food production could considerably reduce reliance on foreign F&V imports. If 2.8 million households, representing about 10% of the UK's population (assuming an average household size of 2.4 [ONS, 2021]), who do not currently grow food started growing on average 163.6 kg of produce (including potatoes) annually, the median amount found in our study, their total production would amount to roughly 460,000 t $year^{-1}$. This would be the equivalent of 5.5% of the total national F&V supply and 8.7% of imports in 2021 (by weight) (Defra, 2020). As a comparison, the level of domestic F&V self-sufficiency (including potatoes) provided by household production following the Dig for Victory campaign was 18% (by value) (Defra, 2017). However, increasing household food production will require greater availability of growing space. Research has demonstrated that there is considerable land suitable for food production in urban areas, where the majority of the population lives (Edmondson, Cunningham, et al., 2020), but only a small proportion of this is currently dedicated to horticulture. Moreover, national provision of allotments has been declining steadily over the decades, and there are important socio-economic inequalities in access to land that put the most deprived neighbourhoods, which could benefit most from better availability of nutritious fresh produce, at a disadvantage (Dobson et al., 2020).

Household food production could contribute to multiple Sustainable Development Goals (SDGs) (Nicholls et al., 2020) and play an important part in increasing the resilience of the UK food system while improving diets and related health outcomes, which could particularly benefit those with limited physical or financial access to F&V (PHE, 2019). Building capacity among the public to produce their own F&V will require increased provision of growing space as well as promoting access to the skills needed to grow, prepare, cook and preserve produce to maximise nutritional and self-sufficiency benefits (Lavelle et al., 2020). Crucially, we need to find ways to overcome socio-economic challenges to upscaling household F&V production, especially among those most affected by low F&V intakes, such as low-income families and children (NHS Digital, 2019).

Here, our diary-based approach provides the first long-term evidence of the role household F&V production could play in increasing household F&V self-sufficiency, promoting F&V consumption and potentially reducing food waste. Thus, our study is an important addition to existing literature that provides an evidence base to support policy-decisions to expand household-level F&V production.

AUTHOR CONTRIBUTIONS

Boglarka Z. Gulyas and Jill L. Edmondson designed and conceptualised the research. Boglarka Z. Gulyas performed data collection and analysis and drafted the manuscript. Jill L. Edmondson supervised the project and edited the manuscript.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that supports the findings of this study are available in the supplementary material of this article.

ETHICS STATEMENT

This project was granted ethical approval by the Department of Animal and Plant Sciences (now School of Biosciences), The University of Sheffield (project ref. 035588).

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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